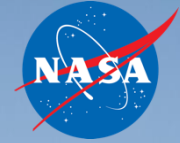


March 11, 2022



ARTEMIS

NASA's Exploration Ground Systems Program
Technology Demonstrations and Risk Reduction
for Sustainable Surface Operations

2022 IEEE Aerospace Conference
Paper 2506 (12.0302)





EXPLORATION GROUND SYSTEMS

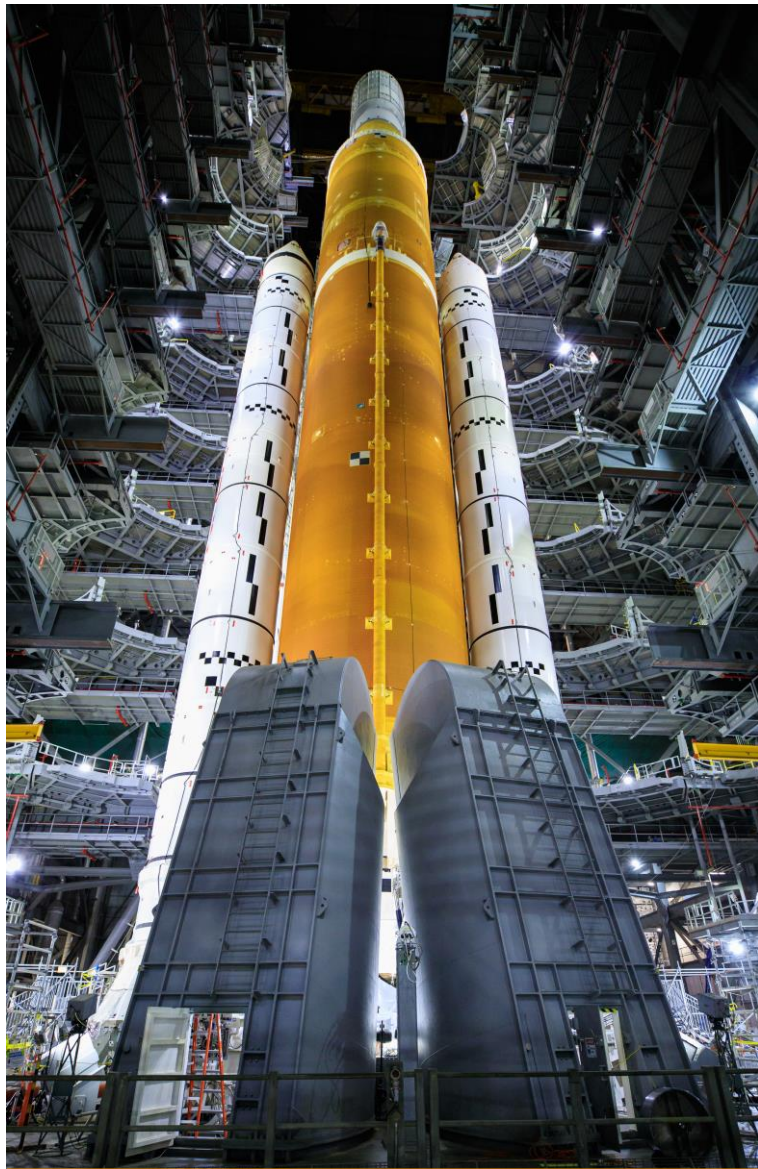
Structures Required to Support Launch

Developing and operating the systems and facilities necessary to process and launch rockets and spacecraft during assembly, transport and launch.

Including:

- Vehicle Assembly Building
- Mobile Launcher
- Crawler Transporter
- Launch Control Center
- Pad 39B

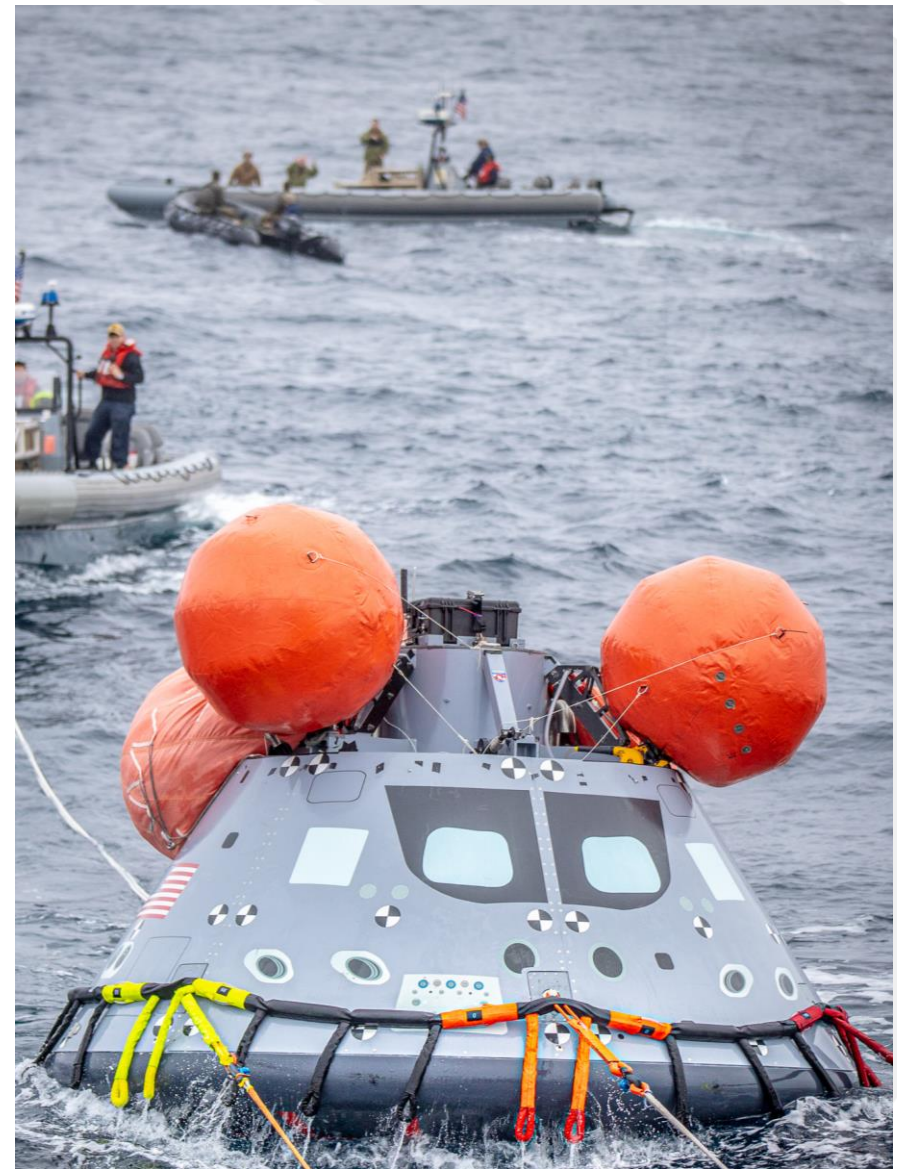
ARTEMIS



BUILD.



LAUNCH.



RECOVER.

ARTEMIS

Vision

***Lead Innovation and Technology Infusion
within Exploration Ground Systems (EGS) to
reduce overall Production & Operations
(P&O) costs***

Mission

***To promote Technology Implementation &
Maturation that strategically aligns with the
EGS Program***

Core Tenet

***Do Not Impact critical path operations of the
EGS Program***



◆ Strategic Alignment

- NPR 7123.1 (NASA Systems Engineering Processes and Requirements) - Section 5.1 (Life Cycle) - program/project approach for maturing and assessing technology is typically captured in a Technology Development Plan
- EGS Program Strategic Plan (PSP), Systems Engineering Management Plan (SEMP), Strategic Technology Infusion Management Plan (STIMP), and Kennedy Space Center Engineering Processes
- EGS PSP Goal - Optimize investments in technology to inform decisions and enable mission success

◆ Implementation Approach

- Evaluate mature capabilities for ground systems implementation - state-of-the-art technologies that require little to no development and/or are being used throughout the industry.
- Demonstrate technology advancements in parallel “shadow” mode, on a non-interference basis, with critical processes or operations.
- Validate equivalent performance and/or improved capability to augment (simplify, reduce costs/manpower) current operations and maintenance (O&M) tasks.
- Transition/Implement (successfully demonstrated) mature technologies into architecture (systems and processes).

◆ Alignment with Agency Technology and Innovation Initiatives

- Integrated Exploration Capabilities Gaps - identify gaps between current capabilities and those needed to enable Artemis architectures
- NASA Technology Taxonomy 2020 - TX13 Ground, Test, and Surface Systems
- NASA Small Business Innovation Research/Technology Transfer (SBIR/STTR) Program - Focus Area 16 Ground & Launch Processing
- Leverage ground technologies and capabilities that are extensible to O&M of infrastructure and systems on other planetary surfaces.

EGS Technology Infusion Strategic Initiatives

QUICK RESPONSE



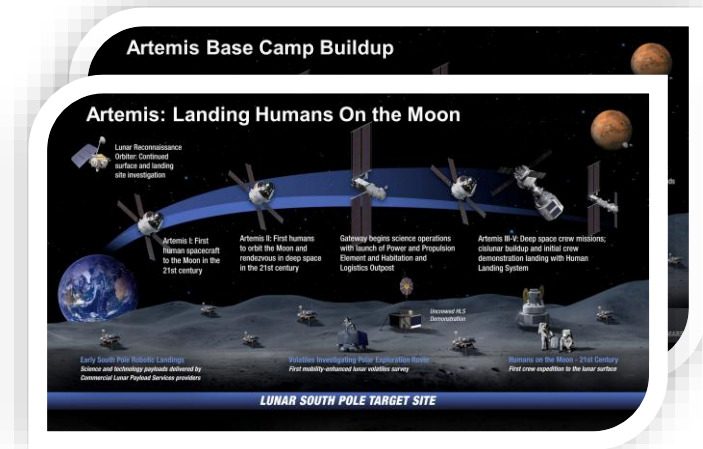
- ◆ **Subject Matter Experts (SMEs) from multiple disciplines of relevance to EGS**
 - the “Brain Trust”
- ◆ **Quick Response Tools and Capabilities**
 - to address operations, element, and engineering concerns and challenges
- ◆ **Engineering/Performance Gaps**

TECHNOLOGY & INNOVATION CALL



- ◆ **Annual NASA Solicitation**
 - new innovations in capabilities, infrastructure, and processes
- ◆ **Requesting Ideas to address:**
 - Schedule Risk Reduction
 - O&M Costs Reduction
 - Increased Reliability & Mission Availability
 - Safety & Health Enhancement
 - High Priority Capability Gaps for Artemis Missions

CAPABILITY GAPS



- ◆ **Provides Information:**
 - Capability Gaps based on upgrades
 - Using Mission Architecture and Requirements documents for Artemis II & Beyond
 - Path forward for top technology investments
- ◆ **Technology/Development Gaps**

Aerogel Bulk-Fill Insulation System for ML Cryo Piping

Goal: Provide a new aerogel-based insulation technology option and simplified operational process for ~80 Mobile Launcher (ML) field cans as an alternative to traditional methods (e.g. wrapping with multilayer insulation and lengthy evacuation process to achieve high vacuum). Aerogel particles are loaded and system backfilled with CO₂ to provide partial vacuum inside the field can.

Result: The KSC CryoTestLab developed a method to install a bulk-fill aerogel insulation system for field cans connecting vacuum-jacketed sections of Liquid Hydrogen (LH₂) and Liquid Oxygen (LOX) cryogenic piping. <https://youtu.be/yXE9kHyg6jl>



Demonstration in CryoTestLab



Aerogel Insulation for
ML Field Cans

Custom Aerogel Filter for SLS LH2 Umbilical System

Goal: Design a custom "Heckle Filter" for protecting the Hazardous Gas suction lines connected to the LH₂ Umbilical Insulation Can as part of the SLS cryogenic propellant loading system.

Result: The KSC CryoTestLab built three kits for use on the umbilical system, which included an insulation system with aerogel blanket and aerogel bulk-fill materials. The new particle-trapping type filter unit was successfully tested through a long-duration LH₂ flow and will be implemented within the EGS architecture as a standard fixture on the umbilical system.



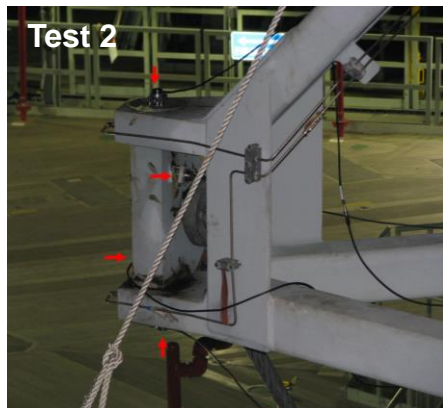
EGS Technology Demonstrations - Quick Response

<https://www.nasa.gov/feature/kennedy-teams-get-inventive-for-artemis-i>

Acoustic Emission System

Goal: Use the KSC Applied Physics Lab (APL) rapid response Acoustic Emission (AE) System, a Non-Destructive Evaluation (NDE) capability, to locate the source of an unknown “popping” sound heard during rotation, accompanied by visible vibration, in the ML1 Crew Access Arm (CAA). The system locates noises caused by sudden changes in pressure, temperature, or load.

Result: The AE sensors were placed at key locations on the CAA support assembly to help triangulate where the sound originated. The setup ruled out the ML structure as the source. The data helped the team determine the path forward for Artemis-I (avoiding a potential significant work stoppage) and for Artemis-II and ML2.



4 AE sensors attached (red arrows) in test configurations to find sound



Mid-IR Fire Detector False Alarm Field Limiting Cones

Goal: Provide a capability to mitigate/limit the multiple occurrences of new Pad Mid-Infrared (IR) fire detector false alarms experienced during testing from flare stack hydrogen flame reflections.

Result: The KSC APL developed cones for attachment to the Mid-IR (hydrogen) fire detectors, that did not alter the capability of the IR fire detectors to detect a flame, to limit their field of view and improve reliability and performance for leak detection/monitoring during hazardous operations.



Mid-IR Fire Detector with Cone Attachment in the Lab (top) and installed at Pad B (right)



EGS Technology Demonstrations - Quick Response

<https://www.nasa.gov/feature/kennedy-teams-get-inventive-for-artemis-i>

UV Hydrogen Flame Simulator Tool

Goal: Provide a capability to validate the performance of the new Ultraviolet (UV) hydrogen fire detectors in the field to mitigate the need to remove them from their position for testing and calibration.

Result: The KSC APL developed a prototype handheld “selfie stick” device that can be held in front of the new UV hydrogen (H₂) fire detectors to validate the performance in the field. The machined hardware, optical assembly, electronics, and software are complete and functionality has been demonstrated in that the unit runs autonomously and will alarm a UV fire detector.



UV Fire Detectors pointing at vehicle area requiring the UV H₂ Flame Simulator Tool

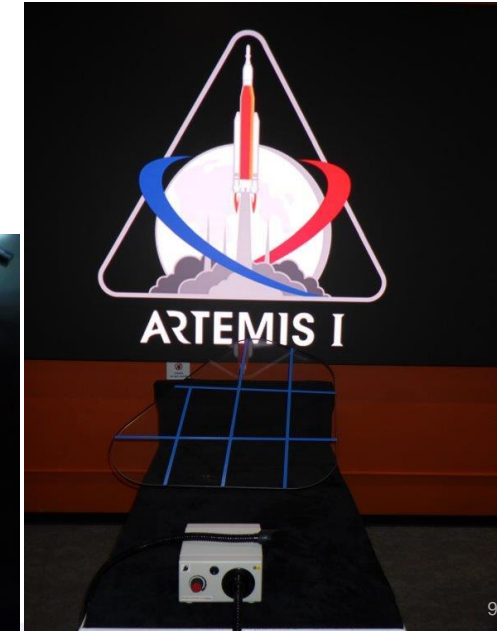
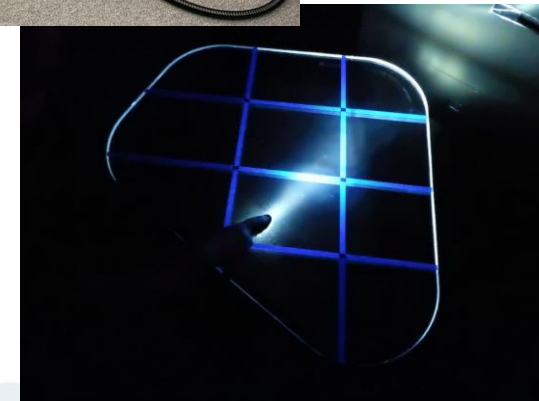


UV H₂ Flame Simulator (right) aimed at a UV Fire Detector (left)

Orion Window Inspection Tool

Goal: Develop a surface light optimizing tool to support inspection of the Orion Capsule Windows at the pad prior to launch. Limited accessibility makes window inspection prior to flight difficult.

Result: The KSC APL designed an Orion Window structured light inspection tool that guides light from an LED source through a fiber bundle to a small Plexiglas/rubber prism which couples light into a window to locate defects. The tool complies with established O&M requirements and specifications and allows for an easier window inspection at the pad, ensuring no defects in Orion’s windows.

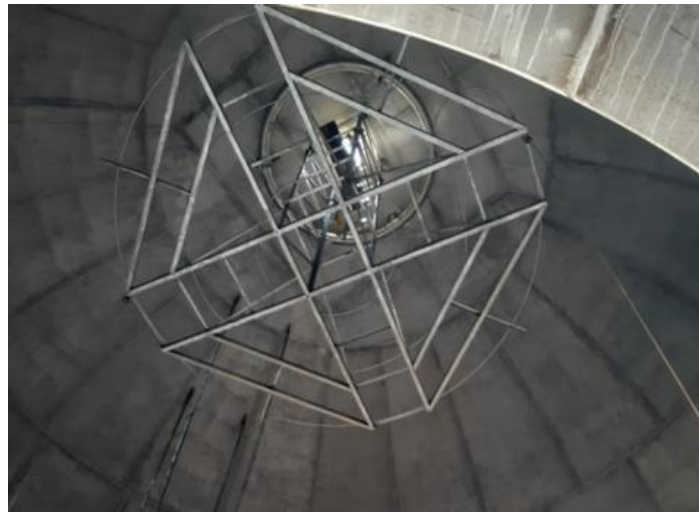


EGS Technology Demonstrations - Multi-year

Launch Pad 39B LH2 Storage Tank Technologies

Goal: Implement two technology options in the construction of the new 1.25 Million gallon LH2 storage tank at Pad 39B.

Result: Incorporation of glass bubbles bulk-fill thermal insulation (in lieu of perlite power) to increase tank thermal performance with an estimated 46% reduction in boil-off losses; and an Integrated Refrigeration and Storage (IRAS) System heat exchanger assembly inside the tank, which when paired in the future with an external refrigerator can enable new capabilities with enhanced operational flexibility.

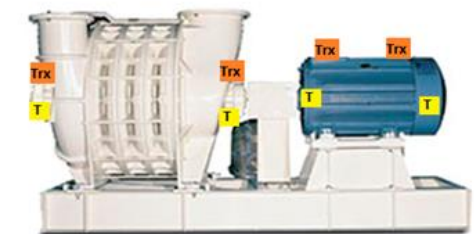


IRAS Heat Exchanger Assembly -
View from inside Sphere

Remote Monitoring of EGS Components

Goal: Develop a capability to perform on demand Condition based maintenance (CBM), utilizing real-time sensor measurements to remotely monitor and determine the condition of EGS components and data analytics to provide early detection of potential future maintenance events (i.e., failures, breakdowns) and determine the most cost-effective time for maintenance.

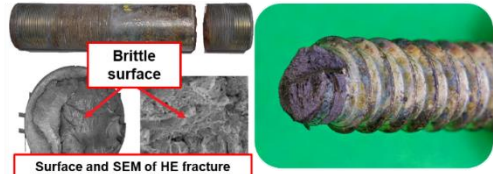
Result: Pad B Environmental Control System blower/motor skids were instrumented with vibration, temperature, and RPM sensors for real-time remote monitoring and data collection to demonstrate CBM for increased asset operational availability, decreased downtime, optimized personnel/property safety, and reduced cost.



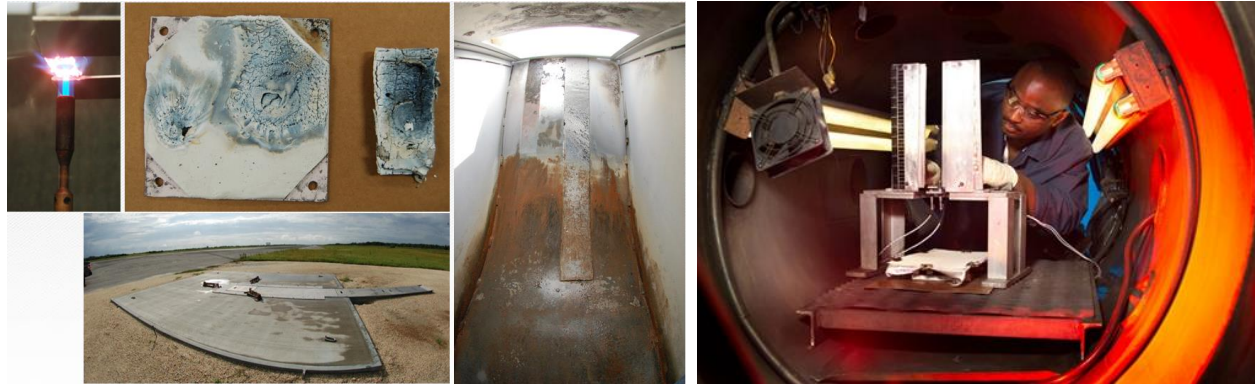
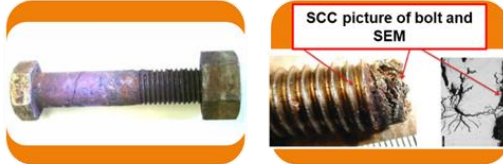
Sensors on each Pad B ECS
Blower / Motor Skid
Triaxial accelerometers (4),
Resistance Temp Detectors (4),
and Tachometer (1)

EGS Technology and Innovation Call Selections (Dec 2019)

Hydrogen Embrittlement (HE)



Stress Corrosion Cracking (SCC)



Silicone Ablative Material Qualification

MSFC Rocket Engine Exhaust Testing Capability (left)
WSTF Flammability Testing per NASA-STD-6001 Test 1 (right)
Completed



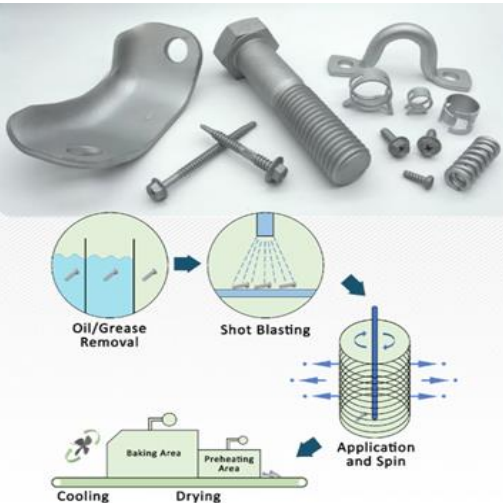
Propellant Handlers Ensemble (PHE) Environmental Control Unit (ECU) Improvements



Automated Tool Control System



O365 Teams Pilot within EGS



Materials Options for High Strength Alloys on Ground Support Structures



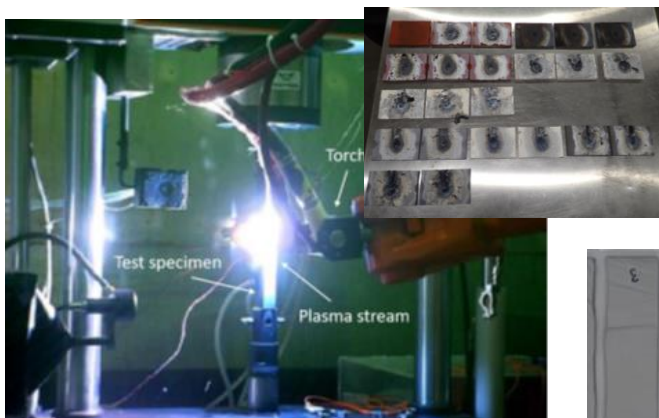
Multiphysics Prediction Capability for Launch Environment Modelling the Water-Based Ignition Over-Pressure/ Sound Suppression (IOP/SS) System **Completed**

EGS Technology Demonstrations from the Innovation Call

Silicone Ablative Material Qualification

Goal: Perform the necessary qualification testing of heat-resistant silicone ablative materials for use on steel launch structures and Ground Support Equipment, update the Qualified Products List and modify the qualification procedure of KSC-SPEC-F-0006B (Heat and Blast Protection Coating Materials & Application Methods)..

Result: KSC with support from MSFC and WSTF completed qualification testing of silicone ablative materials, including one developed specifically for use on launch pads, to provide seven new material options that are lower cost, have longer shelf life, and are more commercially available for multiple EGS appropriate areas and applications.



Marshall Space Flight Center (MSFC)
Plasma Torch Testing and
KSC Post-Test Specimens (top)

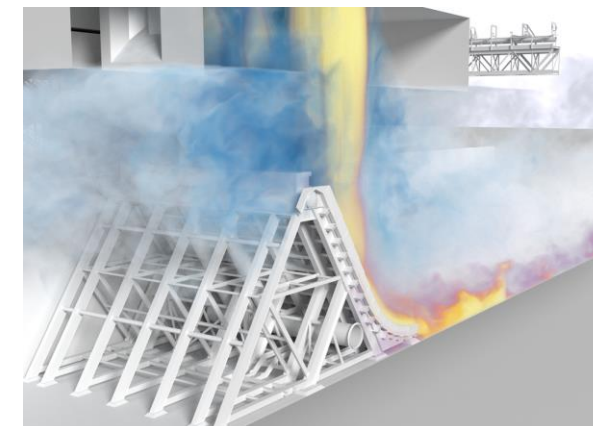
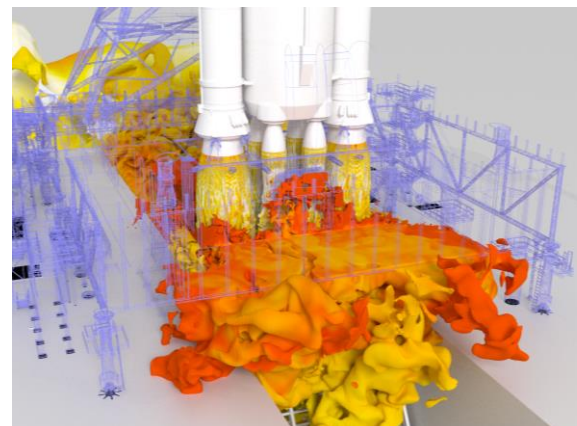


White Sands Test Facility
Flammability Testing and
KSC Post-Test Specimens
(bottom)

Multiphysics Prediction Capability for Launch Environment - Modelling the Water-Based IOP/SS System

Goal: Develop multi-physics analysis capability to accurately model the effects of the water-based Ignition Overpressure and Sound Suppression (IOP/SS) System in the prediction of the launch acoustic environment, to assess the risk of damage to the KSC ground systems and launch infrastructure.

Result: Kennedy and Ames developed diffuse interface multi-fluid models for solving multicomponent/multiphase flow conditions (including water), validated them against flight and experiment data, and applied full-scale simulation to SLS/EGS Pad 39B launch environments.



LC-39B Simulations of SLS Launch Gas Flow
without IOP/SS (left) and with Multiphase water based IOP/SS (right)

EGS Technology and Innovation Call Selections (Oct 2020)



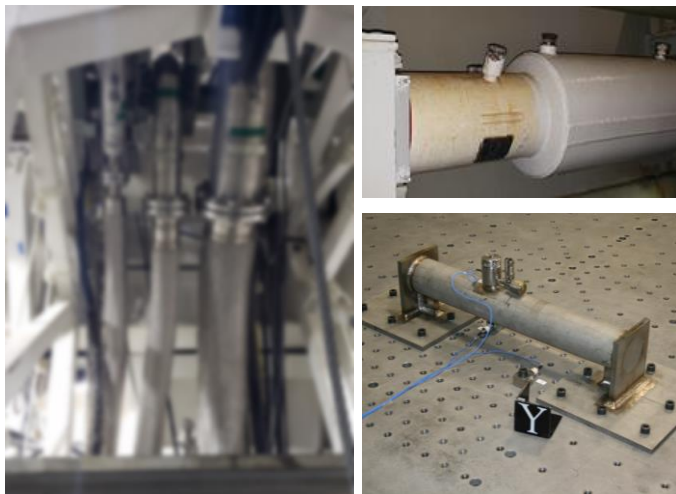
Simplified LOX Dewpoint Testing
Completed

**Improved Ultrasonic Leak
Detector**
Completed



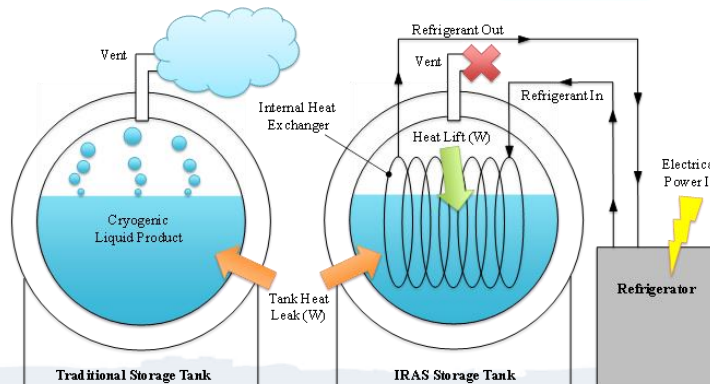
**Exposure and Evaluation of Corrosion-
Resistant Alloys at KSC**
Completed

**More Efficient Methods to Remove, Prepare,
and Repair Coatings for GSE Structures**
Completed

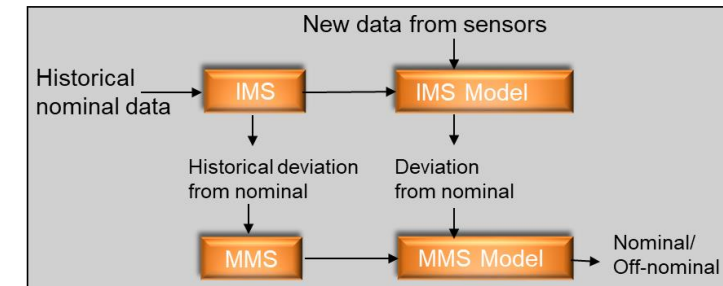


**Remote Monitoring of Cryogenic
Vacuum Section Readings**

**Foundational Steps Toward
Full Control LH2 Storage**
Completed



**High Efficiency
Cryogenic
Propellant Transfer
Lines**
Completed



**Capabilities for Online
Anomaly Detection
of ECS Blower/Motor Skids**

EGS Technology Demonstrations from the Innovation Call

Exposure and Evaluation of Corrosion-Resistant Alloys

Goal: Reanalyze 20-year exposed corrosion-resistant steel (CRES) EGS components, using an expanded suite of higher resolution analytical methods to understand corrosion mechanisms and service life degradation and make informed decisions in the design, operations and maintenance phases for EGS components (i.e. tubing on ML, cryo systems, piping, and for long-term service).

Result: Validated that the current use of CRES alloys is correct based on 20 years of performance, and determined limitations due to exposure of alloys in the acidic and long-term marine environment. Results will be presented at DoD Corrosion Prevention Technology and Innovation Symposium in August 2022.



Weathered CRES Tubing Assemblies at the KSC Beachside Atmospheric Corrosion Test Site after 20 years.

More Efficient Methods to Remove, Prepare, and Repair Coatings for GSE Structures

Goal: Evaluate commercially available methods for coating removal and repair that are smaller, portable, environmentally-friendly and can be applied in more challenging contamination-limiting or hard to reach areas across KSC.

Result: The new methods selected for coating removal and repair, vacuum-based power tools and vacuum abrasive blasting, were validated to meet the NASA-STD-5008 coatings standard and improve KSC processes for corrosion control and maintenance. EGS applicable areas for use of these updated methods include the VAB interior, Crawler Transporter confined spaces, and Pad B.



Needlegun



Grinder



Vacuum-based power tools and adaptable vacuum blast options

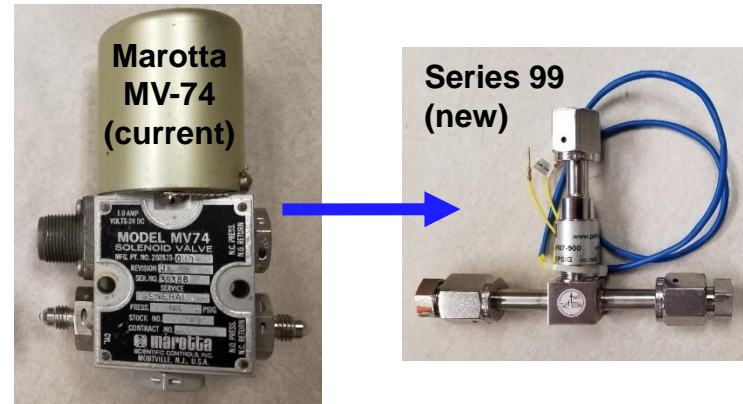


Portable vacuum backpack

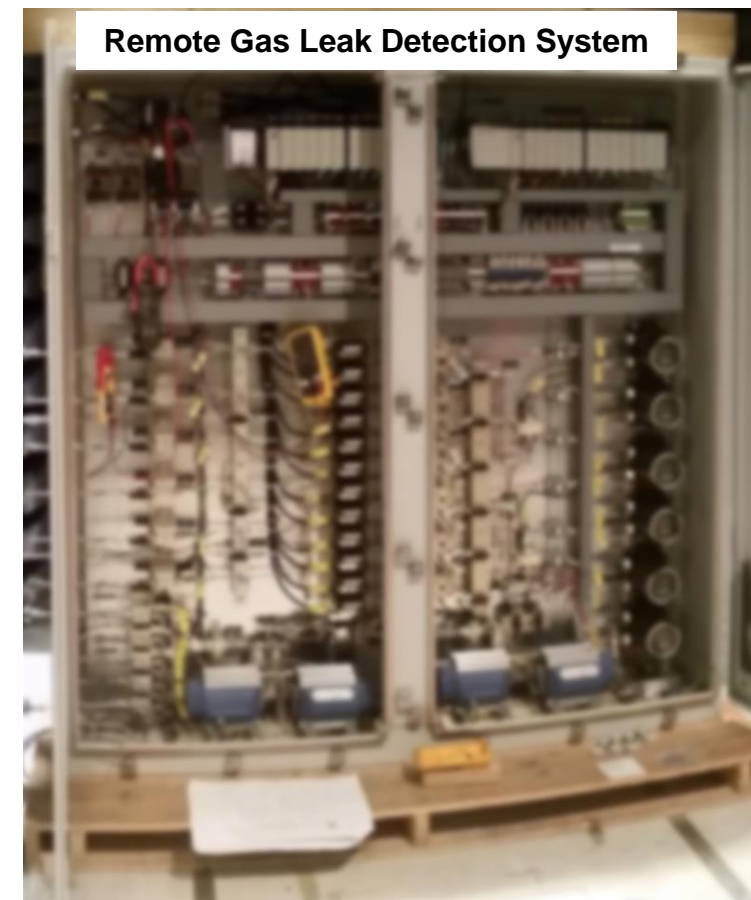
EGS Technology and Innovation Call Selections (Oct 2021)



Microphone Phased Array to identify noise sources and plume impingement zones during Artemis II launch



Pulse-Width Modulation Valve Controller
for Improved Instrument Performance
(better leak integrity and lower cost than current valves used for Haz Gas Leak Detection)



Multi-channel Gas Sensor Systems
(medium fidelity, portable, rapid deployment, multiple sample line capability) for Hydrogen Detection / Characterization that is similar to the ML RGLDS

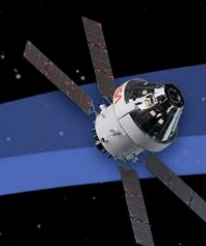
Artemis: Landing Humans On the Moon



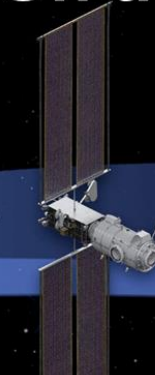
Lunar Reconnaissance Orbiter: Continued surface and landing site investigation



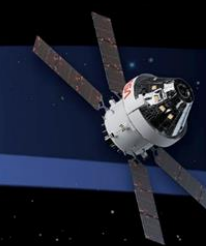
Artemis I: First human spacecraft to the Moon in the 21st century



Artemis II: First humans to orbit the Moon and rendezvous in deep space in the 21st century



Gateway begins science operations with launch of Power and Propulsion Element and Habitation and Logistics Outpost



Artemis III-V: Deep space crew missions; cislunar buildup and initial crew demonstration landing with Human Landing System



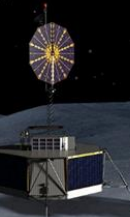
Early South Pole Robotic Landings

Science and technology payloads delivered by Commercial Lunar Payload Services providers



Volatiles Investigating Polar Exploration Rover

First mobility-enhanced lunar volatiles survey



Uncrewed HLS Demonstration



Humans on the Moon - 21st Century

First crew expedition to the lunar surface



LUNAR SOUTH POLE TARGET SITE

Artemis Base Camp Buildup

First lunar surface expedition through Gateway; external robotic system added to Gateway; Lunar Terrain Vehicle delivered to the surface

Sustainable operations with crew landing services; Gateway enhancements with refueling capability, additional communications, and viewing capabilities

Pressurized rover delivered for greater exploration range on the surface; Gateway enables longer missions

Surface habitat delivered, allowing up to four crew on the surface for longer periods of time leveraging extracted resources. Mars mission simulations continue with orbital and surface assets

Lunar Terrain Vehicle (LTV)

Crew
Landing
Services

Pressurized
Rover

Fission
Surface
Power

ISRU Pilot
Plant

Surface
Habitat

SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

MULTIPLE SCIENCE AND CARGO PAYLOADS | U.S. GOVERNMENT, INDUSTRY, AND INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

- ◆ **Low-Loss, High-Efficiency Storage, Distribution, and Conservation of Cryogenic Fluids and Commodities through Passive, Active, and Vacuum Jacket Means**
 - Reduce Hydrogen boil-off losses, improve/optimize fill rates while maintaining liquid properties, minimize transfer losses, reduce reliance on expert operators for routine, labor intensive activities (autonomous propellant loading), optimize storage and distribution of propellants (e.g., green, toxic, or cryogenic) for use at launch complex.
- ◆ **Cryogenic/Non-Hazardous/Toxic Fluids Leak, Fire Detection and Mitigation**
 - Area surveillance and hazard sensing systems to detect and identify, spills, leaks, increased background percent of commodities, and fires of cryogenic, green, hypergolic and toxic fluids and gases in storage areas as well as monitoring of operational areas when personnel are present.
- ◆ **Corrosion Prevention, Detection, and Mitigation**
 - Corrosion detection under coatings, corrosion inhibitors, environmentally friendly coatings (no/low VOC), corrosion preventative compounds and protective coatings, new coating options for the Qualified Products List, corrosion-resistant materials and coatings to minimize inspection, maintenance, repair, and refurbishment requirements (composites and ablatives).
- ◆ **Integrated Systems Health Management (ISHM)**
 - Reduce ground operations maintenance and processing time with on-site inspection and anomaly detection and identification, fault isolation and diagnostics, prognostics, repair, mitigation, and recovery, decision-making tools, autonomous command and control to automate complex and time critical decision making, small robotic inspectors to identify and resolve problems in difficult-to-access spaces, and measurement systems.

◆ Precision Automated Alignment and Positioning Systems

- Real-time, rapid, and quantifiable systems that allow for accurate, controlled, and timely placement of large hardware for element-to-element integration during vehicle processing.

◆ Advanced Ground Crew Work Instructions and Procedures Display

- Overlay electronic procedures, directions, and engineering schematics on top of the actual system in the user's visual field of view for the work as it is being performed to monitor user actions, provide directions, real-time guided-troubleshooting, diagnosis and repair, or certify that the process has been performed correctly.

◆ Helium Usage Reduction Technologies

- Eliminate/reduce/substitute the use of Helium where possible, real-time in-situ measurement to allow using only the minimum amount of Helium needed to meet the engine specifications, purge systems optimization, and alternative purge approaches for hydrogen.

◆ Health and Safety Systems for Operations

- Increase health and safety of operations personnel through virtual hazardous operations modeling, improved (on-demand, lighter-weight) Personal Protective Equipment, hazardous environment personnel monitoring systems, and automated/autonomous hazardous operations.

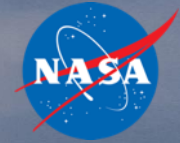


- ◆ **Technology demonstrations to reduce overall P&O costs for the lifecycle of the EGS Program.**
 - Ground and launch systems processing of lunar and Mars mission architectures
 - Propellant production for ground and surface applications (i.e. Methane)
 - Large-Scale Propellant Servicing Capabilities for Nuclear electric propulsion Mars mission concepts
 - Nuclear Payload Processing and Launch Site Approvals

- ◆ **Technology demonstrations on the ground provide risk reduction for Sustainable Surface Operations**
 - The EGS Program can provide a ground analog / simulations for surface operations
 - To identify and validate human/automation roles and tasks
 - To reduce reliance on humans to perform tasks
 - For accommodating ground communication delays

- ◆ **Exploration Capability Gaps that need to be addressed for Sustainable Surface Operations include:**
 - Surface Systems Standardized Architectures and Interfaces
 - Surface Operations Multi-Element Systems Engineering and Integration
 - Surface Systems Design for Supportability (maintainability, repairability, redundancy, resilience, spares, reusability)
 - Surface Systems Automated/Autonomous cryogenic loading, transfer, servicing, and storage of commodities; Planning and Scheduling; Inspection, Maintenance and Repair
 - Surface Systems Health Determination and Fault Management, Logistics Management and Reliability, Launch & Landing Site Preparation, Commodity Management, and Automated Umbilicals and Dust Tolerant Interfaces

QUESTIONS?



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